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Controlling Nitrogen Oxides

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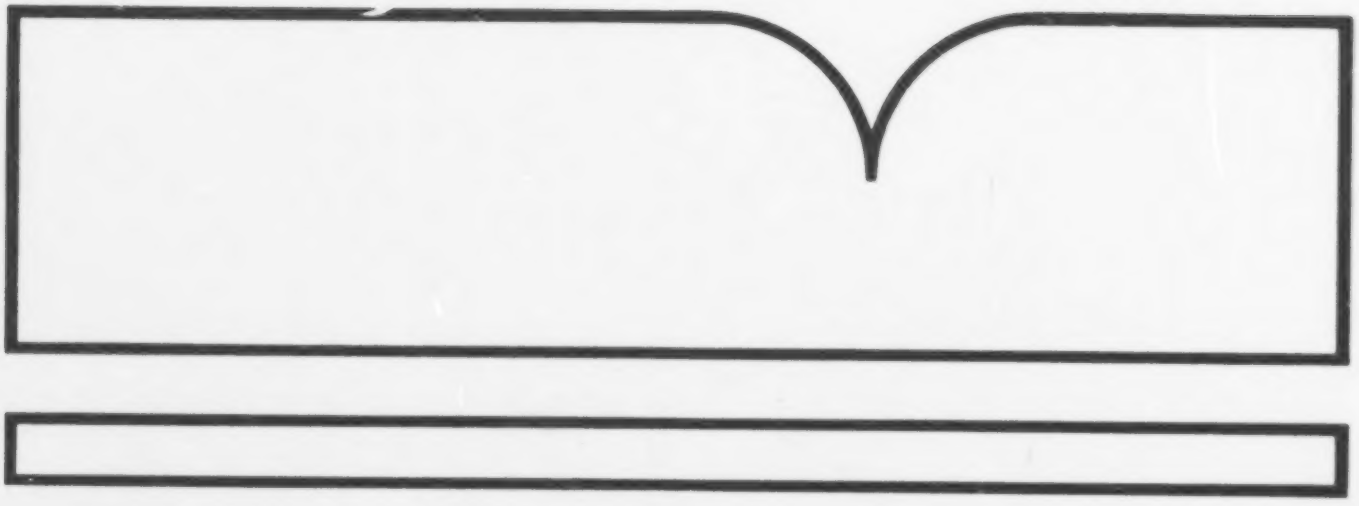

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This publication briefly summarizes the Office of Research and Development's Nitrogen Oxide Control R&D program in an easily read, non-technical format.

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Office of Research and Development

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Research Summary

Controlling Nitrogen Oxides

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Recent research indicates that nitrogen oxides (NO_x) could be one of the most troublesome air pollutants of the 1980's. More than 20 million metric tons of NO_x are annually polluting our air as a result of the widespread combustion of fossil fuels in power plants, industrial boilers, and automobiles and trucks. If present trends continue, nitrogen oxides emissions could grow by 50% over the next twenty years, with the increases coming primarily from industrial sources.

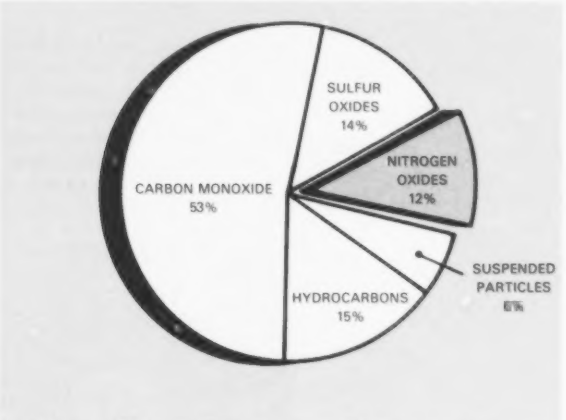
Present levels of NO_x emissions already pose a significant threat to our health and environment. This threat is due not only to the widespread nature of combustion sources, but also to the unusual chemical properties of NO_x. Nitrogen oxides are directly harmful to human health, and are precursors of photochemical oxidants such as ozone, the major component of urban smog. They can also be converted into nitric acid, one of the two principal components of acid precipitation.

As the Nation increasingly turns to coal as a bridge to cleaner sources of energy, we must recognize that, at current levels of controls, coal-fired plants emit more nitrogen oxides than gas and oil-fired plants. Since natural environmental processes are not able to cope with even current NO_x emissions, we must move rapidly to improve NO_x control technologies for all major sources.

The EPA is actively working with other Federal agencies and the academic, industrial, and private research communities to develop viable combustion technologies which will strictly limit NO_x emissions. We have prepared this Research Summary to inform you of the status of our efforts to make improved control technologies available as soon as possible.

Stephen J. Gage
Assistant Administrator
for Research and Development

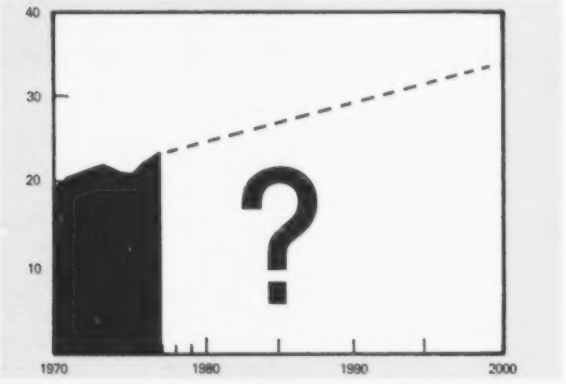
Each year more than 20 million metric tons of nitrogen oxides (NO_x) are released into the atmosphere as a result of fuel-burning activities in the United States. While fires and other natural occurrences result in about 10 times the amount of NO_x generated by man, naturally occurring nitrogen oxides tend to be dispersed over very large areas. NO_x produced as a combustion by-product from energy-related technologies developed by man can create local pollutant levels that are 10 to 100 times greater than natural concentrations. Nitrogen oxides are emitted from combustion sources primarily as nitric oxide (NO). Atmospheric processes may convert the nitric oxide to nitrogen dioxide (NO_2) and nitric acid (HNO_3).



Source: National Air Quality, Monitoring, and Emissions Trends Report, 1977, EPA, December 1978.

creasing missions

In 1977 nitrogen oxides accounted for approximately 12% of the total estimated U.S. pollutant emissions of 194 million metric tons. Nitrogen oxide emissions have steadily increased in recent years. The EPA's latest air pollution projections indicate an approximately 50 percent increase in NO_x emissions to the year 2000.



Effects of NO_x

Concern over nitrogen oxide emissions is based on known cases of human health problems and environmental damage caused by NO_x or atmospheric compounds derived from NO_x. Probably the most important ecological effect of NO_x is its contribution of the formation of photochemical oxidants commonly known as smog. NO_x reacts with hydrocarbons in the presence of sunlight to form these oxidants. Ozone is the main constituent of photochemical oxidants, and can have severe effects on the respiratory system. Breathing smog irritates the lungs and can seriously aggravate asthma and other respiratory diseases. Coughing, eye irritation, headaches, and throat pain are commonly experienced during exposure to smog.

Exposure to NO_x itself is believed to increase the risks of acute respiratory disease and susceptibility to chronic respiratory infection. Nitrogen dioxide (NO_2) contributes to heart, lung, liver, and kidney damage. At high concentrations, this pollutant can be fatal. At lower levels of 25 to 100 parts per million, it can cause acute bronchitis and pneumonia. Occasional exposure to low levels of NO_2 can irritate the eyes and skin.

Photo Credit: EPA Documerica

In addition, nitrogen oxides are toxic to vegetation. Many plants can metabolize low concentrations of NO_x. However, higher concentrations reduce growth and seed fertility.

Acid Rain

NO_x emissions also affect the environment by contributing substantially to the acid rain problem. Through a series of complex atmospheric reactions nitrogen oxides can be converted to nitric acid, which may then be deposited in the form of rain or snow. Rainfall tested in various parts of the country has become much more acidic over the past 40 years. Nearly half of this present acidity is due to nitric acid. Acid rainfall in

the Adirondack Mountains of New York has reduced or destroyed commercially and recreationally important species of fish in at least 90 lakes. Other areas of the United States such as northern Minnesota and Wisconsin are beginning to experience similar effects.

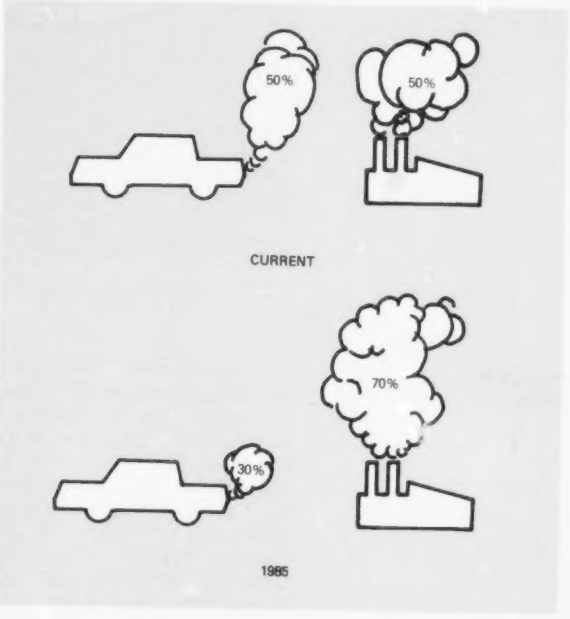
Thermal versus Fuel NO_x

Nitric oxide is formed by two chemical processes that occur during combustion. In one process the heat of combustion causes the oxidation of nitrogen in the air. In the other process it is the nitrogen in the fuel which becomes oxidized. The former process results in what is commonly known as thermal NO_x, and the latter in fuel NO_x. The formation of thermal NO_x is strongly dependent upon the amount of heat available and can be controlled by reducing the temperature. The formation of fuel NO_x, on the other hand, is primarily dependent upon the amount of oxygen available.

One should bear in mind that the ultimate goal of nearly all nitrogen oxides control processes is to either convert the harmful oxidized forms of nitrogen (NO, NO_2) to harmless molecular nitrogen (N_2), or to prevent the oxidation of nitrogen in the first place. Molecular nitrogen is a colorless and odorless gas that constitutes 78% of the atmosphere by volume.

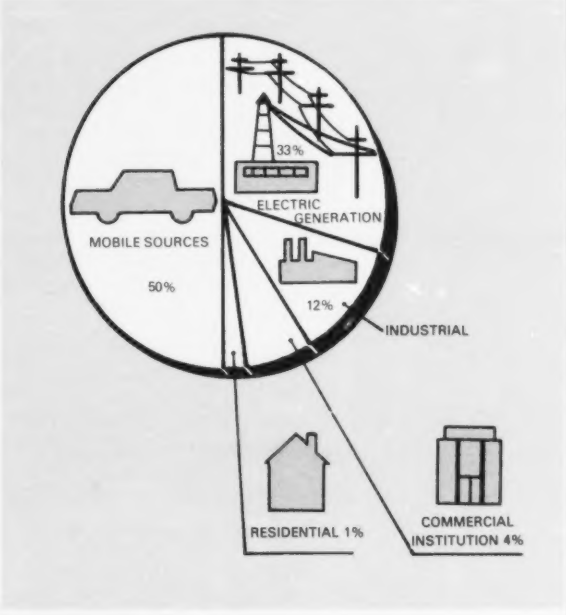
NO_x Sources

About half of the NO_x emissions from fuel combustion come from stationary sources such as furnaces and boilers. The other half come from automobiles and other motor vehicles.



By 1985 stationary sources are estimated to account for 70% of manmade NO_x emissions. Part of the reason for growth in stationary source NO_x emissions is the growing trend toward using coal for electrical generating stations and industrial boilers. Coal is the most abundant fuel in the U.S., but it also presents the most complex emission control problems. Because there is more nitrogen in coal than in most other fuels, burning coal produces more NO_x than burning oil or gas.

Nearly one-third of all NO_x emissions are released from electrical generating stations. Another 12 percent come from industrial furnaces, boilers, and manufacturing processes.



Research Goals

The Environmental Protection Agency's Office of Research and Development (ORD) is developing inexpensive methods to reduce NO_x emissions from various combustion technologies without causing operating problems, shortening equipment life, or increasing emissions of other pollutants. Most of the ORD research is performed in conjunction with the Federal Interagency Energy/Environment Research and Development Program. More than 15 agencies perform research under this EPA-sponsored program established to ensure a coordinated and cost-effective approach towards Federal energy/environmental R&D.

Reducing Emissions

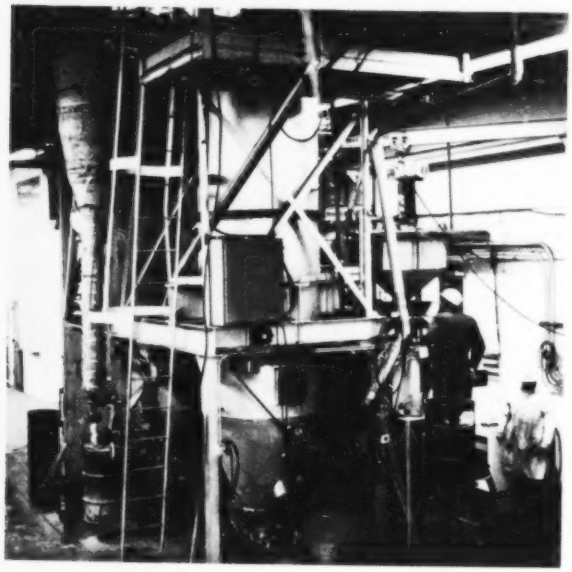
The most promising methods of reducing NO_x emissions currently are:

Before burning:
- fuel denitrogenation

During burning:
- staged combustion
- catalytic combustion

In exhaust gas:
- flue gas treatment
- catalytic emission control

Prime responsibility for the development of NO_x control technology lies with the EPA's Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina (IERL-RTP). Additional research is being conducted at the Environmental Sciences Research Laboratory in Research Triangle Park (ESRL-RTP), and through the Headquarters Office of Environmental Engineering and Technology in Washington, D.C.

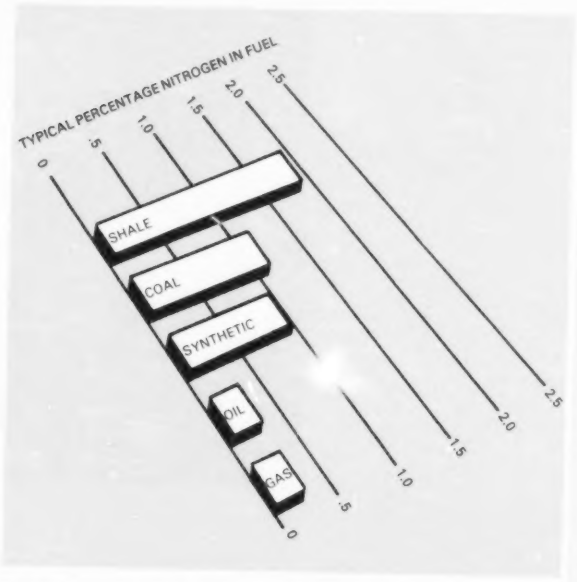


Fuel Denitrogenation

One approach to reducing nitrogen oxide emissions is to remove a large part of the nitrogen contained in fuels. Various industries are conducting research into methods of denitrogenation, and ORD's Industrial Environmental Research Laboratory in Research Triangle Park has been actively involved in these studies.

Nitrogen is removed from liquid fuels by mixing the fuel with hydrogen gas, heating the mixture, and using a catalyst to cause the nitrogen in the fuel and the gaseous hydrogen (H) to unite. This produces ammonia (NH_3) and cleaner fuel. Researchers are working to discover better catalysts and to find ways of reducing the deposition of carbon on the catalyst surface. Such deposition decreases the efficiency of the catalyst.

This technology can reduce the nitrogen contained in both naturally-occurring and synthetic fuels. It could become a particularly important means of controlling NO_x emissions from liquid fuels derived from oil shale and coal. Their levels of fuel-bound nitrogen are higher than the levels found in naturally occurring oil.

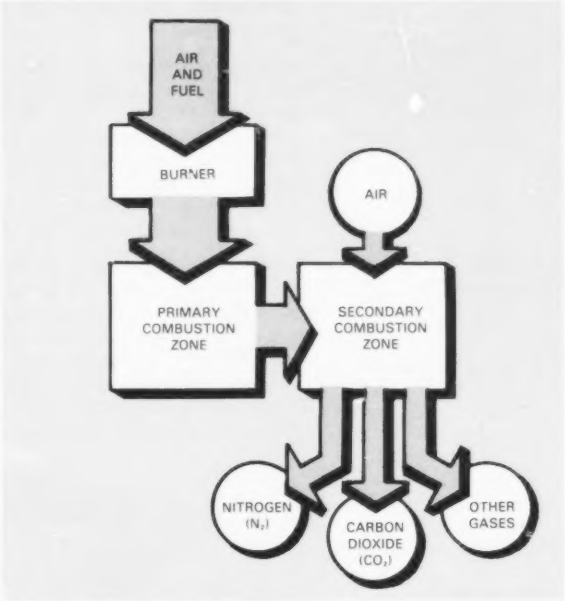


Staged Combustion

Staged combustion processes developed at the Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina (IERL-RTP) significantly reduce NO_x emissions. Staged combustion is applicable to a wide range of fuels and energy facilities including pulverized coal burners and small-scale industrial boilers.

In the initial stage of combustion, the air supplied to the burners is less than the amount needed to completely burn the fuel. During this stage, fuel-bound nitrogen is released but cannot be oxidized, so it forms stable molecules of harmless molecular nitrogen (N_2). Other components of the fuel are also released without being fully oxidized. These include carbon particles and carbon monoxide. By adding a second stage of combustion where there is more air in the fuel-air mixture, the carbon and carbon monoxide can be burned, converting them to carbon dioxide.

Modifying existing coal furnaces to achieve a staged combustion process has resulted in a 30% to 50% reduction in NO_x emissions. In addition to reducing NO_x emissions, limiting the amount of air during the combustion process increases the efficiency of converting fuel to usable heat.



ulverized oal urner

A new coal burner design based on staged combustion may reduce NO_x by as much as 85 percent. The burner produces a fuel-rich primary combustion zone and controls the fuel-air mixing. These conditions lead to preferential conversion of the nitrogen in the coal to molecular nitrogen (N_2). In conventional burners, this fuel nitrogen is the primary source of NO_x. Additional air is introduced from the periphery of the burner to complete combustion in a secondary zone. The design also results in low levels of carbonaceous emissions, consistent with high energy efficiency.

This burner design has been fired at rates comparable to those required for boiler application. The evaluation of the performance of the burner in actual field conditions will be carried

out on two industrial and two utility boilers over the next several years.

Boiler Corrosion Prevention

Before industry invests its money in a new NO_x control technology, it needs assurance that the technology will not have major operating problems. Laboratory engineers are working with a committee of representatives of electrical utility companies to address potential problems in adapting the staged combustion technology to pulverized coal-fired boilers.

A major concern within the electric utility industry is that the reduced amount of air available in the first stage of combustion may cause the formation of iron sulfide on the metal surfaces inside the boiler. Iron sulfide would then progressively corrode the metal in the walls of the boiler. The Office of Research and Development has obtained a utility boiler equipped for staged combustion, and is measuring the effects of corrosion over several years.

Although the extent of possible corrosion from staged combustion has not yet been determined, scientists at IERL-RTP are already experimenting with techniques to prevent such corrosion. In one experiment, some of the metal surfaces in the boiler have been replaced with a metal alloy thought to be corrosion resistant. In another, air is forced into the boiler along a metal wall, forming a curtain of air. This curtain of forced air should prevent iron sulfide from being formed.

Residential Oil Furnaces

Conventional oil-fired residential furnaces introduce oil and air into a firebox where the burning occurs. This combustion either heats air or water which is circulated through the house. A new furnace design has been developed and is undergoing a two-year field evaluation. The design incorporates several features to reduce pollution while increasing fuel efficiency. A burner has recently been developed that reduces both NO_x and carbonaceous emissions.

Photo Credit: Rockwell International

A primary innovation in the residential oil furnace was to remove a controlled amount of heat from the firebox, and thus reduce the formation of thermal NO_x. The field tests have shown that this newly developed oil-fired residential furnace has reduced NO_x by 65 percent. Oil consumption was also reduced by an average of 15 percent. Thus fuel savings have been achieved while simultaneously protecting the environment.

Small-Scale Industrial Boilers

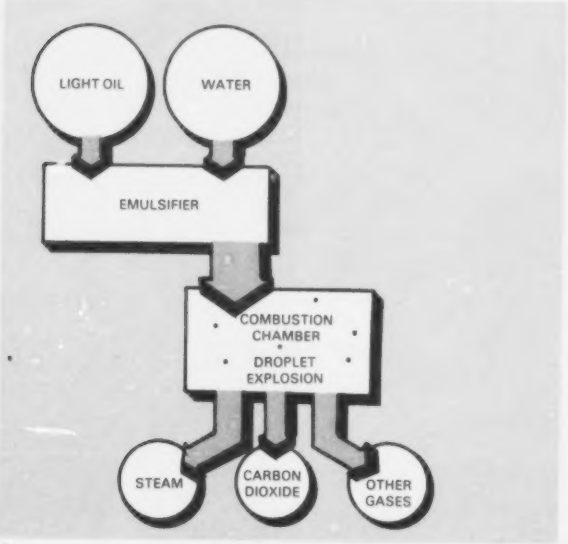
Boilers used for light industry and for heating large buildings are usually manufactured and assembled as a unit, prior to shipment to various users. Typical boilers of this type burn No. 2 or No. 6 fuel oil. The No. 6 fuel oil is a heavy residual product from refineries, and about 70% to 80% of the NO_x emitted from burning this fuel is derived from the nitrogen chemically bound in the oil.

Reducing the amount of oxygen available during the initial combustion stage has been demonstrated to be a viable technique to reduce NO_x emissions from these boilers. The reduced amount of oxygen, however, results in incomplete combustion so that the amount of carbon particulates emitted in the exhaust increases.

A project is underway to develop a burner for these boilers that will limit NO_x emissions while maintaining the high efficiency of the boiler and preventing the formation of carbon particulates. Experiments are being conducted that will identify the combustion properties of the several No. 6 fuels on the market, and provide information on the size and distribution of droplets being sprayed from the fuel nozzle.

Water/Oil Emulsions

One of the methods of reducing NO_x emissions from oil-fired combustion systems is to mix water with the oil before it is sprayed into the burner. Water decreases the combustion



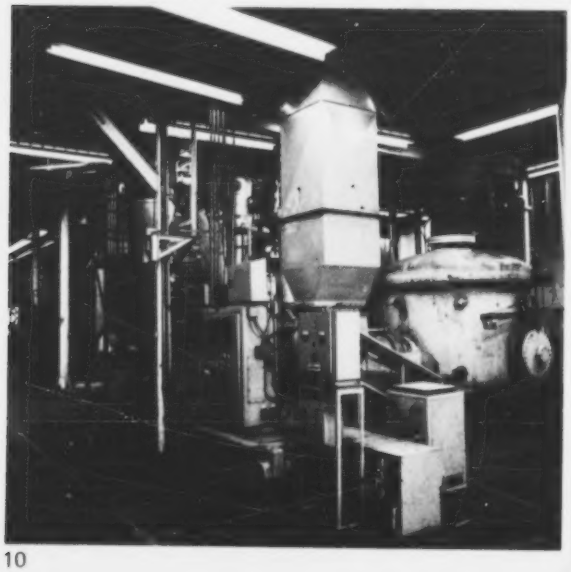
temperature and can reduce NO_x emissions from burning light weight oils by as much as 15%.

Studies are being conducted to evaluate the applicability of using water/oil emulsions in various small-scale industrial boilers and residential furnaces. A significant added advantage in using these emulsions is that they reduce the emission of particulates. When water is mixed into the oil, each oil droplet sprayed into the firebox has several tiny water droplets inside. The heat existing in the firebox makes these water droplets flash into steam and explode the oil droplet. Increasing the surface area of the oil enables it to burn faster and more completely. A reduction in particulate emissions can be achieved regardless of whether light oils or heavy oils are being burned.

When the amount of water added to the oil is properly controlled, it does not reduce the efficiency of the boiler or furnace. In fact, the efficiency of a poorly adjusted burner can be increased slightly by putting up to 18% water in the emulsion. The increased efficiency results from the more complete burning of the oil.

Gas Turbine Engines

Gas turbine engines are used primarily to provide additional electrical power during the few hours of each day of highest demand. Utility boilers that produce most of our electrical power require a relatively long period of time to start up. Gas turbine engines can be started and shut down quickly. The engines usually burn natural gas or No. 2 fuel oil, both of which have relatively low levels of nitrogen. The primary focus of NO_x control for gas turbine engines has been to reduce the amount of thermal NO_x generated during combustion. The standard approach has been to inject water into the combustion area, thereby reducing the burning temperature and the amount of NO_x formed. Unlike adding water in an oil-



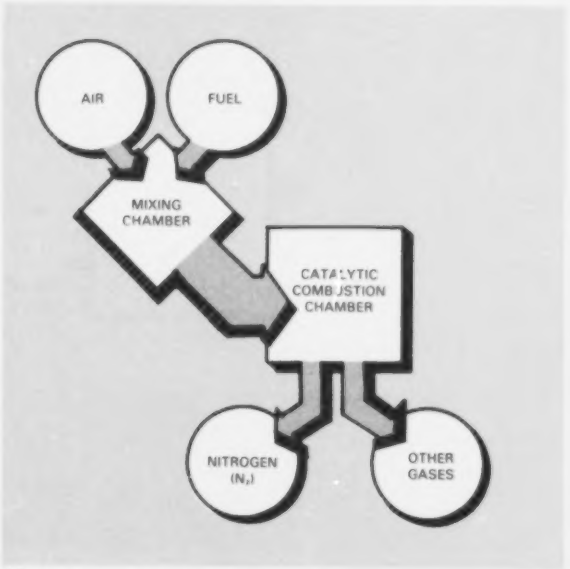
water emulsion, simply spraying water into the combustion zone decreases efficiency. Typically, the engines' efficiency is reduced by 2 percent to 5 percent. Water for injection systems is in short supply in many arid parts of the country, and where it is available, it must be purified.

EPA's Industrial Environmental Research Laboratory in Research Triangle Park undertook the task of developing combustion NO_x controls without using water. A major breakthrough in design of the gas turbine engine enabled them to successfully burn the fuel in a staged combustion process. This was accomplished by altering the shape of the combustion chamber so that the gases coming from the initial combustion zone are compressed at the point where additional air is added to complete the combustion. This new design can reduce uncontrolled NO_x emissions from 200 parts per million (ppm) to 20 ppm.

Catalytic Combustion

Another method of reducing pollutant emissions is to use a catalyst to achieve oxidation of fuel rather than high temperature. Experiments are being conducted to develop catalytic combustion systems for both stationary gas turbine engines and small industrial boilers. Natural gas, propane, and vaporized distillate oil are being used as fuel for the catalytic combustor. Fuel and air are mixed to the desired ratio and introduced into a chamber containing the ceramic or metal catalyst. Various compounds are being tested to identify the most desirable catalysts.

Catalytic combustors for gas turbines have reduced NO_x emissions to well below 10 ppm. Catalytic combustion is more



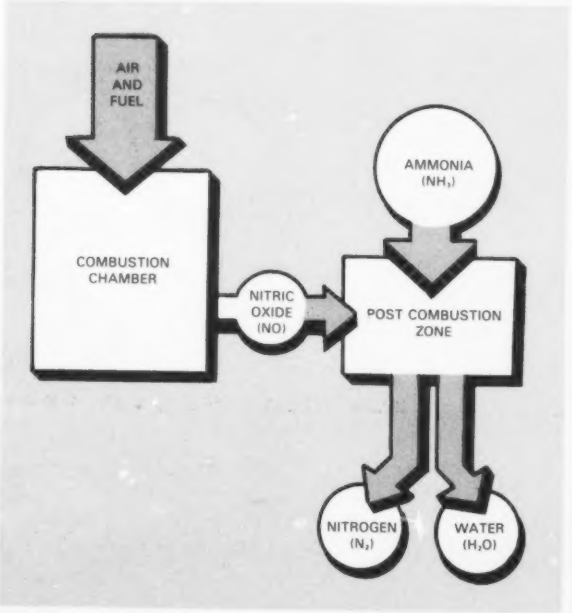
difficult to apply to stationary boilers because of the need to operate with reduced air content to achieve high thermal-efficiency. Preliminary tests indicate that low NO_x emissions will result from catalytic combustion in these industrial boilers, as well.

Ammonia Injection

Ammonia is an unoxidized nitrogen-containing compound. IERL-RTP is evaluating a process developed by private industry in which ammonia is injected into a boiler in the post combustion zone. The ammonia reacts with the NO_x, reducing it to harmless molecular nitrogen.

$$\underset{\text{AMMONIA}}{NH_3} + \underset{\text{NITRIC OXIDE}}{NO} \longrightarrow \underset{\text{NITROGEN}}{N_2} + \underset{\text{WATER}}{H_2O}$$

In order for this process to be successful, the ratio of ammonia to nitric oxide and the temperature must be carefully controlled. Ammonia injection has been experimentally shown to reduce NO_x emissions in oil, gas, and small coal-fired systems. Experiments performed to date indicate that ammonia injection can reduce NO_x emissions by more than 60%. This technique could be used to supplement combustion control techniques where very low NO_x emission levels are required.



Flue Gas Treatment

NO_x emissions can also be reduced by removing them from the exhaust gases that are released from burners. There are two studies currently underway at the Industrial Environmental Research Laboratory in Research Triangle Park to develop and test such equipment.

One of these studies focuses on NO_x removal alone and operates on the same principal as ammonia injection. Ammonia is added to the flue gas prior to the gas passing over a catalyst. The catalyst enables the ammonia to react chemically with the NO_x converting it to molecular nitrogen (N_2) and water. This system promises to achieve as high as 90% removal of nitrogen oxides from flue gases.

In a second study, a process is being developed to remove both NO_x and sulfur oxides (SO_x). The combustion gases are moved across a bed of copper oxide which reacts with the sulfur oxide to form copper sulfate. The copper sulfate acts as a catalyst for reducing NO_x to ammonia. Up to 90% of the NO_x and SO_x can be removed from the flue gas through this process.

Equipment for both kinds of flue gas treatment systems are being installed at two coal-fired electric power generating stations as pilot studies. The NO_x removal process is being tested at the Georgia Power Company's Plant Mitchell in Albany, Georgia. The NO_x/SO_x removal system is being tested at Tampa Electric Company's Big Bend Station near North Ruskin, Florida. This second project is of particular interest because it is the first test of the technology in the U.S., and the first test anywhere in the world on a coal-fired plant.

Motor Vehicle Exhaust

Currently the most promising technology for reducing NO_x emissions from motor vehicles is a special 3-way catalytic converter. The catalyst causes nitric oxide (NO) to oxidize carbon monoxide (CO) and hydrocarbons (HC). In this process, molecular nitrogen, carbon dioxide, and water vapor are released.

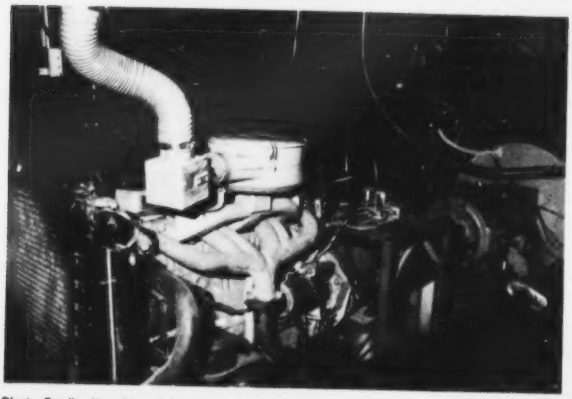
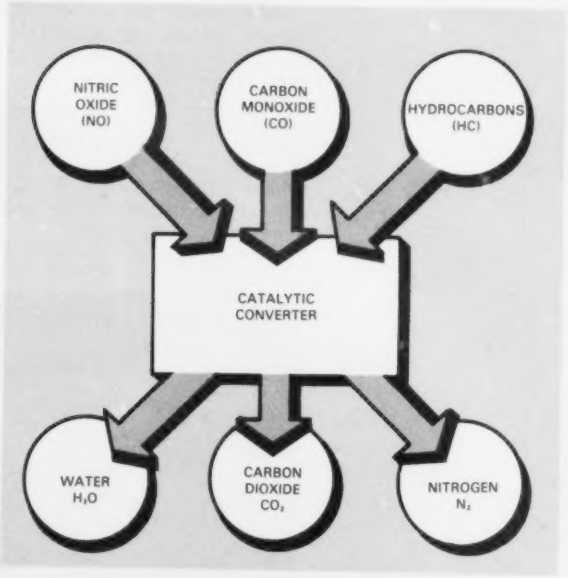


Photo Credit: Ken Altshuler

In order to make this reaction work efficiently, the proportions of NO, CO, and HC entering the catalytic converter must be carefully controlled. This is done by regulating the ratio of air and fuel in the combustion chamber. Too much fuel results in increased CO and HC emissions. Too much oxygen results in increased emissions of nitrogen oxides. An oxygen sensor in the exhaust manifold allows control, while an active feedback device adjusts the mixture of air and fuel in the carburator or fuel injection system.

Tests are being conducted by the Environmental Sciences Research Laboratory to determine the emission rates of pollutants from vehicles equipped with 3-way catalytic converters. Pollutants being measured include nitrogen oxides, carbon monoxide, hydrocarbons, ammonia, hydrogen cyanide, and other toxic compounds. These tests are conducted on both properly and improperly tuned vehicles operated under a variety of normal and adverse environmental conditions. The results of the EPA tests currently underway will contribute toward determining whether this device will need to be modified before being widely marketed.



Auto Exhaust NO_x Measurement

Hand in hand with the need to develop emission control technology is the need to develop accurate methods of measuring the volume of specific emissions.

A project is underway at the Environmental Sciences Research Laboratory in Research Triangle Park to develop a method of measuring the NO_x emissions from motor vehicles equipped

with 3-way catalytic converters. Conventional methods for measuring NO_x are not appropriate and tend to overestimate NO_x emissions.

A new measurement technique using atomic hydrogen (H) is being developed. Hydrogen atoms reduce nitrogen dioxide (NO_2) in the exhaust to nitric oxide (NO). This nitric oxide plus any nitric oxide formed by fuel combustion reacts with additional hydrogen atoms in a way which emits a very small amount of light. The light can be measured as a low level electric current. This technique enables scientists and engineers to accurately measure the NO_x in vehicular emissions containing other nitrogen compounds.

Photo Credit: Ken Altshuler

Jet Engine NO Measurement

Most NO_x from jet engines is in the form of nitric oxide (NO). Conventional sampling methods use a probe to capture a specific volume of emissions, which are then cooled to prevent continued chemical reaction. Measurements of nitric oxide by the conventional method are not reliable because they allow the spontaneous oxidation or reduction of the nitrogen compounds on the surface of the sampling probe.

A refined electro-optical measuring technique is being developed by ESRL-Research Triangle Park to accurately

measure the nitric oxide from jet engines. This work is being performed in cooperation with NASA, the U.S. Air Force, and the Federal Aviation Administration. The measuring technique makes use of the fact that nitric oxide absorbs ultraviolet light. A beam of this light is shone through the engine's exhaust plume while a spectrometer measures the amount of light absorbed. By calculating the difference between the ultraviolet light absorption which occurs when the engine is running and when it is not running, the concentration of nitrogen oxides can be calculated.

Electro-optical measurement techniques are currently being used to monitor NO and NO_2 from stationary sources. Their application to measuring nitric oxide in jet engine exhaust is unique and difficult because of the high temperature of the exhaust gases. The plume temperature from the stack of a utility or industrial plant may be about 150°C, but the exhaust from jet engines may be as much as ten times hotter.

In addition to finding ways to reduce NO_x emissions from combustion equipment, ORD laboratories are investigating methods of reducing NO_x emissions from manufacturing processes such as glass-making and nitric acid production.

Glass Manufacturing

A project to reduce NO_x emissions during the manufacture of glass is being conducted by ORD's Industrial Environmental Research Laboratory in Cincinnati. In conventional glass-making processes, the silicon and other materials for producing glass are heated in a furnace. Over 50 percent of the energy used to heat the furnace is lost in exhaust gases. Experiments are underway to alter the furnace design so that the

exhaust gas is used to preheat the raw materials for glass-making. Preheating has a number of advantages in the glass-making industry. It reduces the amount of fuel needed in the furnace, the amount of air drawn into the combustion process, the temperature required in the furnace to melt the silicon material, and the length of time that the material must remain in the furnace. Reductions in fuel use, air intake, and combustion temperature have resulted in the decrease of both fuel-bound NO_x emissions, and thermal NO_x emissions. The costs that the glass industry could save by using less fuel are an additional incentive to make use of the preheating process.

Nitric Acid Production

About 70% of the nitric acid (HNO_3) produced in the U.S. is used to manufacture fertilizer. Other uses include the production of industrial explosives, separating gold and silver, pickling steel and brass, and photoengraving. Nitric acid is produced by oxidizing ammonia (NH_3). The oxidation is never totally complete, however, and uncontrolled emissions from nitric acid plants are typically on the order of 1000 to 3000 ppm NO_x.

Several NO_x control techniques are available and are being used. The IERL Branch Laboratory in Edison, New Jersey has been developing a technique called molecular sieve adsorption. NO_x is removed by converting NO to NO_2 and adsorbing the NO_2. This process results in NO_x concentrations of less than 50 ppm in the emission stream, and the NO_2 which is collected can be used to produce more nitric acid.

NO_x Transport

In the early 1970's scientists at ORD's Environmental Sciences Research Laboratory in Research Triangle Park noticed that measurements of NO_x in the atmosphere were lower than expected. A series of studies were initiated to determine whether pollutant nitrogen oxides have a short lifespan, and if so, to identify the factors important in converting NO_x to other compounds.

Measurements of nitrogen oxides, photochemical oxidants, and specific nitrogen compounds were made downwind of cities where significant amounts of NO_x were emitted. These cities included St. Louis, Los Angeles, Phoenix, Dayton, Columbus, and Boston. A small plane equipped with instruments for continuous monitoring of the pollutants was flown back and forth downwind of the city monitoring plumes which sometimes extended 20 to 30 miles from the pollution source.

These experiments showed that NO_x does have a short lifespan relative to other pollutants. It may last 6 to 7 hours or as long as two days. The rate at which NO_x is converted to nitrates, nitric acid, and other pollutants depends on such factors as humidity, temperature and the intensity of sunlight.

INDIVIDUAL RESEARCH PROJECTS

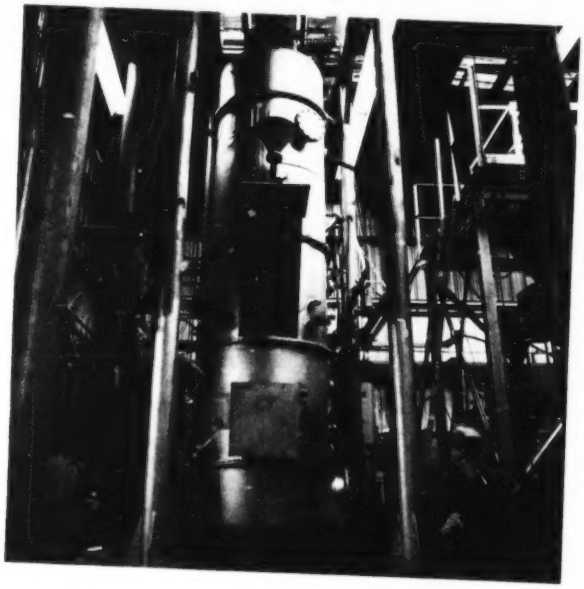
Selected research projects performed by or through the various ORD laboratories or offices are listed below.

Industrial Environmental Research Laboratory — Research Triangle Park, North Carolina

- Environmental Assessment of Stationary Source NO_x Control Technologies
- Effects of Fuel Properties and Atomization Parameters on NO_x Control for Heavy Liquid Fuel-Fired Package Boilers
- Development of Criteria for Extension of Applicability of Low-Emission, High-Efficiency Coal Burners
- Field Testing — Application of Improved Combustion Technology to Power Generation Combustion Systems
- Advanced Combustion Systems for Stationary Gas Turbine Engines
- Fundamental Combustion Research Applied to Pollution Control
- Investigation of NO_x, Nitrate and Sulfate Formation in Laboratory Flames
- Development of Catalyst and System Design Criteria for Catalytic Combustors with Application to Stationary Sources
- Evaluation of Fundamental Combustion Phenomena
- Characterization of Emission and Combustion Performance of Alternate Fuels
- Characterization and Design Evaluation for Commercial Combustion Systems
- Bench-Scale Evaluation of Simultaneous NO_x/SO_x Flue Gas Treatment Technology
- Bench-Scale Evaluation of NO_x Flue Gas Treatment Technology
- Effect of Fuel Sulfur on Nitrogen Oxide Formation in Combustion
- Miniplant Studies in Support of the Fluidized-Bed Combustion Program
- Demetallization of Residual Oils (Phase V — Denitrogenation Catalyst Evaluation)
- Experimental and Engineering Support of the Fluidized-Bed Combustion Program
- Process Automation Investigations for Environmental Process Control
- Emissions Assessment of Conventional Combustion Systems
- Long-Term Optimum Performance and Corrosion Tests of Combustion Modifications for Utility Boilers
- Control Technology Application and Assessment for Industrial Stoker Boilers
- Evaluation of Emissions Control for I.C. Engines
- Application of Advanced Combustion Modification Technology to Industrial Process Equipment

Environmental Sciences Research Laboratory — Research Triangle Park, North Carolina

- Aerometric Field Study in Vicinity of a Large Power Plant in Complex Terrain
- Aspects of Modeling Urban Air Quality
- Design and Fabrication of an Automated Field Monitor for the Measurement of Atmospheric Nitric Acid



- Evaluation of the Accuracy and Validity of Physico-Chemical Air Quality Models
- Kinetic Study of Simulated SO_2, NO_X, RH-Polluted Atmosphere
- Mechanisms of Photochemical Reactions in Urban Air
- Outdoor Simulation of Air Pollution Control Strategies
- Characterization of Emissions from Prototype Motor Vehicles Designed for Low NO_X Emissions
- Investigation of the Dependence of Ambient NO_2 on Precursor Emissions
- Fate of NO_X and Transport of Oxidant
- Mobile Source NO_X Monitor: Hydrogen-Atom Chemiluminescence Method
- Development and Testing of Instrumental Techniques for Nitrogen-Containing Compounds
- Analysis of Jet Engine/Airport Emissions Using Various Remote Sensing Methods
- Characterization of Gaseous Emissions from Stationary Sources by Remote Sensing
- Studies of the Effect of Environmental Variables on the Collection of Atmospheric Nitrate and Development of a Sampling and Analytical Procedure
- Development of a Flashlamp-Induced Fluorescence Ambient Air NO_2 Monitor

Office of Environmental Engineering and Technology — Washington, D.C.

- A Study to Support the Development of New Source Performance Standards for Control of SO_2, NO_X and Particulates from Combustion Boilers
- Energy Related Air Pollution Monitoring Standard Reference Materials, Instrumentation and Methods

FOR FURTHER INFORMATION

Publications

- NO_x Control Review
  A quarterly technical newsletter prepared by EPA's Industrial Environmental Research Laboratory in Research Triangle Park, North Carolina.

  Individuals interested in receiving the newsletter should write to:

  Editor
  NO_x Control Review
  US EPA, MD-65
  Research Triangle Park, NC 27711

- EPA Research Outlook. February 1979. EPA-600/9-79-005. 140 Pages.

  A concise description of the EPA's plans for future environmental research.

- EPA Research Highlights. December 1978. EPA-600/9-78-040. 70 Pages.

  Highlights of the EPA research and development program of 1978.

- EPA/ORD Program Guide. October 1979. EPA-600/9-79-038. 85 Pages.

  A guide to the Office of Research and Development—its organizational structure, program managers, and funds available for contracts, grants, and cooperative agreements.

- Energy/Environment III. Proceedings of the Third National Conference on The Interagency Research and Development Program. October 1978. EPA-600/9-78-002. 386 Pages.

  The proceedings of an annual conference discussing energy/environment issues, sponsored by the Federal Interagency Energy/Environment Research and Development Program.

Other Research Summaries

- EPA Research Summary: Acid Rain. October 1979. EPA-600/8-79-028. 23 Pages.

  A brief discussion of what is presently known about the acid rain phenomenon and the EPA's R & D program to learn more about the problem.

- EPA Research Summary: Oil Spills. February 1979. EPA-600/8-79-007. 15 Pages.

  A concise description of EPA's oil spills R & D program.

Information on the availability of these publications may be obtained by writing to:

Publications
Center for Environmental Research Information
US EPA
Cincinnati, OH 45268

Technical Reports

- Environmental Assessment of Stationary Source NO_x Control Technologies: First Annual Report. March 1978. EPA-600/7-78-046. 105 Pages.
(PB-279 083, $6.50)

- Control Techniques for NO Emissions from Stationary Sources. AP-65
(PB-190 263, $0.70)

- Emission Characterization of Stationary NO Sources. June 1978. EPA-600/7-78-120A
(PB-284 480, $5.25)

- Preliminary Environmental Assessment of Combustion Modification Techniques:
  - Volume I. October 1977. EPA-600/7-77-119a
(PB-276 680, $6.00)
  - Volume II. October 1977. EPA-600/7-77-119b
(PB-276 681, $16.50)

- Proceedings of the Third Stationary Source Combustion Symposium:
  - Volume I. Utility, Industrial, Commercial, and Residential Systems. February 1979. EPA-600/7-79-050a. 255 Pages.
(PB-292-539, $10.75)
  - Volume II. Advanced Processes and Special Topics. February 1979. EPA-600/7-79-050B. 316 Pages.
(PB-292-540, $11.75)
  - Volume III. Stationary Engine and Industrial Process Combustion Systems. February 1979. EPA-600/7-79-050c. 177 Pages.
(PB-292-541, $9.00)
  - Volume IV. Fundamental Combustion Research and Environmental Assessment. February 1979 EPA-600/7-79-050d. 234 Pages.
(PB-292-542, $9.50)

Technical Reports may be obtained by writing to:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

or by calling (703) 557-4650

Conferences and Workshops

The Office of Research and Development periodically sponsors various conferences, workshops and seminars to inform environmental scientists, engineers, policy makers, and the interested public of the latest research and development accomplishments. Individuals interested in information about upcoming conferences should write to:

ORD Conference Coordinator
Center for Environmental Research Information
US EPA
26 W. St. Clair
Cincinnati, OH 45268

Questions or Comments

The Office of Research and Development invites you to address any questions or comments regarding the EPA nitrogen oxide control research program to the appropriate individuals listed below:

Topic	Contact
Stationary Source Control Technologies	Joshua Bowen Industrial Environmental Research Laboratory, MD-65 Research Triangle Park, NC 27711
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Program Coordination/ General Questions	Robert Statnick Office of Research & Development, RD-681 US EPA Washington, D.C. 20460